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Final Report

Digital Paper Technologies for Topographical Applications

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Abstract

This paper examines three different methods for collecting GIS attribute-value data using digital pen and paper maps and forms. Users create features on a digital paper map by ticking the legend entry for that feature on the map with a digital pen, and then marking the location of that feature on the map. In order to enter attribute-value data to that feature, users would either: 1) write the attribute-value data directly on the map, 2) write a linking identifier on the map, and then write that same identifier on a digital paper in a special “InkID” column of an Excel form that has been exported from the GIS system’s database, or 3) write the attribute values in the table *immediately after* having created (or selected) the map feature (called the temporal association method). Among the measures examined were training time for each method, time for entry of features, procedural errors, handwriting recognition errors, and user preference. For these metrics, temporal association was fastest, had fewest procedural errors, and was preferred by most field users. However, the impacts of these different workflows on “back office” GIS personnel was not considered.

1. Introduction

A geographic information system (GIS) stores and displays spatial information, accepts inputs into a geographic database (“geo-database”) underlying that geospatial display, and supports calculations based on the geographic information to support decision-making.

Unfortunately, the complexity of GIS software and end-user computer equipment has made it difficult for field workers, untrained in the intricacies of GIS, to collect needed data. We have addressed this need by developing digital paper and pen mapping software based on Anoto technology that integrates with leading GIS software from Esri (ArcGIS), and TerraGo (GeoPDF). This technology enables untrained users to provide GIS data by marking on digital paper maps using digital pens. Such data is immediately geo-registered by the software and made available for subsequent processing.

Because data collection is via paper and pen, a broad class of end users already knows how to use the device. For example, sixth-grade students have used the technology during Earth Day events in Nashua, NH to indicate on digital paper maps the location of garbage in their city that needed to be picked up. When the data was imported into the city’s GIS system, GPS-equipped garbage trucks could then be routed to the specified locations. (<http://www.adapx.com/sites/default/files/file/capturx-casestudy-nashua-earth-day.pdf>)

Although map markup has many uses, many GIS workflows involve the users’ providing *attribute-value* data for newly created or existing map features. For example, in the past, the US Census Bureau often incorporated an “address canvassing” step in the decennial census, in which a census worker would mark the position of a new housing structure on a map, write a “map spot” label, and then on a subsequent page, would enter that map spot label into a table and provide various attributes about the related housing structure. For example, the worker could indicate that it had 4 bedrooms, two stories, was unoccupied, etc. Many industries that capture geospatial information have very similar attribute-value data collection needs.

To address the need for collecting data via field workers untrained in the intricacies of GIS, we have employed the use of digital pen and paper. This enables the use of existing paper-based work practices, which minimizes training, while providing a digital output that can lead to substantial productivity gains. The question to be addressed in this paper is how to support attribute-value data collection via digital pen and paper.

The paper is organized as follows:

In section 2, we describe the background technologies to be used - digital paper and pen, as well as Capturx™ software that integrates this technology with GIS and forms software. In section 3, we discuss various methods that have been implemented for capturing attribute value data. Section 4 presents the study we undertook to investigate the advantages and disadvantages of each method. Section 5 discusses related work. Section 6 then discusses the results and their implications, followed by the conclusions we draw in Section 7. The appendices provide the study materials and protocol.

2. Background Technology

In this section, we describe the basic digital pen and paper technology and how we have integrated it with standard GIS and spreadsheet systems in order to bridge the analogue/digital gap.

2.1 Digital Pen and Paper

Digital pen and paper technology provides a dot pattern that is printed on a paper document (see Figure 1), and a digital pen that senses that pattern (see Figure 2). Unlike relative-positioning digital pens, these digital pens read not only an absolute position on a page; the pens know precisely what page it is. The pen records the coordinates of the pen on the page, as well as certain meta-data (e.g.'s the page's unique identifier, date, time, etc.). The X-Y data is stored in the pen until it is unloaded or transmitted to another system. Application software then interprets the digital ink markings in the context of the specific piece of paper they were written on. The most successful digital pen/paper technology is by Anoto, AB



Figure 1. Anoto Dot Pattern



Figure 2. Digital pen

(<http://www.anoto.com>).

Various software companies have developed a number of applications that integrate this base technology into commercially viable offerings. Most of those applications enable the user to fill out forms, though the design of the form is usually done by the software vendor. Unique among these software applications are those from Adapx¹, whose Capturx² line of software enables *the end user* to develop their own forms, maps, etc., by integrating digital pen and paper technology with popular software applications, such as Esri's ArcGIS and Microsoft's Excel, OneNote, and SharePoint. In the study described herein, two of these products are used - Capturx for Esri ArcGIS™, and Capturx Forms for Microsoft Excel™.

2.1 Capturx for ArcGIS

Many users who wish to collect GIS-related data in the field find that existing mobile computer systems can be too small, too complex, too expensive, and/or too fragile to be used effectively by their mobile work force. Typically, their field data has been collected via paper and pen, and then rekeyed by the GIS

¹ Pronounced as "Adapts"

² Pronounced as "Capturz"

department or even by the end user into an enterprise database. We built Capturx for ArcGIS to support precisely these workflows and user base.

Capturx for ArcGIS enables a user of Esri's ArcGIS to create "feature-class" data in the field without the user having to manipulate the underlying application, or to know anything about GIS. Figure 3 shows an image of an ArcGIS map for wildland firefighting. It consists of a legend describing a set of symbols that may appear on the map, along with the map itself. The symbols are point, line, and area-based.

Capturx is a plug-in to ArcGIS, and thus operates transparently with it. With the plug-in, a user is able to print a digital paper version of this map, along with the legend, which then becomes a user interface. The user would add feature-class instances of the elements in the paper's legend by ticking them with the digital pen, and then drawing their geospatial extent. Thus, the user could position firefighting information (e.g., proposed bulldozer lines, aerial foam drops, escape routes, etc.) by touching their legend items and drawing them on the map. When the digital pen is docked, or the data is sent remotely via a Bluetooth connection and a mobile phone to a computer running ArcGIS, the geo-database updates are incorporated and made available digitally for validation.



Figure 3. Capturx for ArcGIS wildland firefighting map

Now, the creation of features is only part of the field GIS workflow. Users typically also need to enter or update the values for attributes of those features. Within ArcGIS, each feature classes' attributes and values are kept in a set of database tables. In order to update them, the user needs to provide tabular input in addition to geospatial input. However, ArcGIS (version 9.3.1) does not provide an easy-to-use interface for tabular input suitable for field personnel. Often, Microsoft Excel forms are the field data collection tool of choice, and Excel can be used as a front-end to databases. We thus support this existing workflow using a second digital pen-based Capturx software tool.

2.2 Capturx Forms for Microsoft Excel

Capturx software is integrated directly with Microsoft Office Excel 2007, using the standard Microsoft ribbon, enabling a user of Excel to create a form, to specify field content types, and to create the named range labels needed to export the data from Excel. When the form is printed using the PRINT WITH

CAPTURX button, a digital ‘watermark’ of background dots is created under the form contents. Each field is given a datatype (e.g., date, time, free text, checkbox, text restricted to a specific list of values, etc.) that provides constraints to the handwriting recognizer. When the user fills out the form with the digital pen, the digital ink is first captured (Figure 4a), and then is converted to text (Figure 4b) according to the datatype restrictions specified in the form cell. Not all fields need be converted to text, such as a signature field, or a marking on a body diagram. The user can alternate between seeing the digital ink and seeing the converted text with the INK button. Thus, the product stores *both* the original ink and the converted results, which can be corrected using the CAPTURX REVIEW PANE. Because the software knows precisely which form the pen is writing on, the user can move quickly among documents without having to keep track of the source document and application.

The screenshot shows a Microsoft Excel spreadsheet titled 'Forms.xlsx - Microsoft Excel'. The ribbon has tabs for Home, Insert, Page Layout, Formulas, Data, Review, View, Developer, Add-Ins, and Capturx. The Capturx tab is selected, showing icons for Direct, Capturx, and Design Form. The Design Form icon is highlighted. The main area displays a table with columns A through G. Row 1 contains headers: Link ID, ID 1, ID 2, Kind, Num Lights, and Needs Clean. Rows 2 through 12 contain data entries. Row 8 is highlighted in orange and shows handwritten text in column A: '12345678'. Column A contains handwritten numbers from 1 to 11. The 'Capturx Review Pane' is open on the right side, showing details for Cell A8: Author: subject10, Pen ID: AJX-AAC-7MY-6Q, Date: 3/3/2011 7:45:40 AM. It also shows the cell value '7' and a list of candidates: 7, 1, 4, 2, 9, 3, 5, 6, 0, 8.

	A	B	C	D	E	F	G
1	Link ID	ID 1	ID 2	Kind	Num Lights	Needs Clean	Utility Poles
2	1	1353874	410	unknown	2	<input type="checkbox"/>	
3	2	1353670	520	electric	1	<input type="checkbox"/>	
4	3	1353527	908	electric	0	<input type="checkbox"/>	Method L
5	4	1353834	600	electric	2	<input type="checkbox"/>	
6	5	1353540	2000	electric	3	<input type="checkbox"/>	
7	6	1353559	2100	electric	2	<input type="checkbox"/>	
8	7	12345678	2103	electric	1	<input checked="" type="checkbox"/>	
9	8	none	none	traffic	2	<input type="checkbox"/>	
10	9	1253897	404	electric	1	<input type="checkbox"/>	
11	10	12539185	2101	electric	1	<input type="checkbox"/>	
12	11	12536175	501	electric	1	<input type="checkbox"/>	
13							

Figure 4a. Filled out attribute form with digital ink capture

The screenshot shows a Microsoft Excel spreadsheet titled "Forms - Microsoft Excel". The main table has columns labeled A through I. Column A is "Link ID", B is "ID 1", C is "ID 2", D is "Kind", E is "Num Lights", F is "Needs Clean", and G, H, I are empty. Row 1 contains the column headers. Rows 2 through 17 contain data. Row 2: Link ID 1353874, ID 1 410, Kind unknown, Num Lights 2, Needs Clean (checkbox). Row 3: Link ID 1353670, ID 1 520, Kind electric, Num Lights 1, Needs Clean (checkbox). Row 4: Link ID 1353527, ID 1 908, Kind electric, Num Lights 0, Needs Clean (checkbox). Row 5: Link ID 1353834, ID 1 600, Kind electric, Num Lights 2, Needs Clean (checkbox). Row 6: Link ID 1353540, ID 1 2000, Kind electric, Num Lights 3, Needs Clean (checkbox). Row 7: Link ID 1353559, ID 1 2100, Kind electric, Num Lights 2, Needs Clean (checkbox). Row 8: Link ID ozog 985, ID 1 2103, Kind electric, Num Lights 1, Needs Clean (checkbox). Row 9: Link ID none, ID 1 none, Kind traffic, Num Lights -2, Needs Clean (checkbox). Row 10: Link ID 1253897, ID 1 404, Kind electric, Num Lights 11, Needs Clean (checkbox). Row 11: Link ID 1383985, ID 1 2101, Kind electric, Num Lights 4, Needs Clean (checkbox). Row 12: Link ID 1353675, ID 1 501, Kind electric, Num Lights 1, Needs Clean (checkbox). Rows 13 through 17 are empty. On the right, a "Capturx Review Pane" is open, showing a preview of a handwritten digit "7" and its transcription "7". It also lists "Candidates: 7, 1, 4, 2, 9, 3, 5, 6, 0, 8". Buttons for "Approve" and "Revert" are present.

Link ID	ID 1	ID 2	Kind	Num Lights	Needs Clean			
1	1353874	410	unknown	2	<input type="checkbox"/>			
2	1353670	520	electric	1	<input type="checkbox"/>	Utility Poles		
3	1353527	908	electric	0	<input type="checkbox"/>	Method L		
4	1353834	600	electric	2	<input type="checkbox"/>			
5	1353540	2000	electric	3	<input type="checkbox"/>			
6	1353559	2100	electric	2	<input type="checkbox"/>			
7	ozog 985	2103	electric	1	<input checked="" type="checkbox"/>			
8	none	none	traffic	-2	<input type="checkbox"/>			
9	1253897	404	electric	11	<input type="checkbox"/>			
10	1383985	2101	electric	4	<input checked="" type="checkbox"/>			
11	1353675	501	electric	1	<input checked="" type="checkbox"/>			
12					<input type="checkbox"/>			
13					<input type="checkbox"/>			
14					<input type="checkbox"/>			
15					<input type="checkbox"/>			
16					<input type="checkbox"/>			
17					<input type="checkbox"/>			

Figure 4b. Filled LinkID form with digital ink in Figure 4a converted to text

2.3 Three Methods for Solving the Attributes Problem

We investigated three methods for collecting attribute-value (A-V) data.

1. *On-Map*. Write attribute-value data on the map itself. Thus, a user could write "Diameter=30in" on the map next to or associated with a new or existing feature on the map.
2. *LinkID*. A second general method takes advantage of the ArcGIS capability for joining external database relations with relations in the geo-database. Fortunately, Capturx for Microsoft Excel enables users to fill out forms in Excel that populate a database relation. In order to provide the needed attribute-value update capability, we implemented a method to export an attribute table from ArcGIS as a structure that is readable by Excel, with an automatic population of datatypes and handwriting grammars from the table to the Excel spreadsheet. The Excel table is also provided with metadata that will inform ArcGIS about the datatypes when the data is returned. Then, using Capturx for Microsoft Excel, a user can print such a form digitally, fill it out with a digital pen in the field, and then import the data back into Excel. From there, the handwriting recognition can be validated and the form then imported into the attribute table(s) in ArcGIS, to be coordinated with the map update (creation of features on the map). Since there may be more than one set of attributes and values for any given feature class, the attribute-value update method needs to enable the user to indicate which feature goes with which attribute-value data. One method for doing so enables the user to associate feature with the attribute-values by writing a linking identifier (LinkID) on the map, and entering that same identifier into an ID column in the relevant A-V table. Joining the Excel table with the GIS database then provides the association.
3. *Timing*. Associate the ArcGIS feature with the most recently selected/touched/entered row in the attribute table in Capturx for Excel attribute table entries. Thus, this method uses the timing of map and table update. The remainder of the method is the same as *LinkID*.

In sum, the present study compares these three methods for performing attribute-value updates - writing on the map, using a linking identifier across form and map, and using timing information between map and form update.

In the next section, we describe each of these methods in greater detail.

2.4 Specific Attribute Collection Methods

The overall workflow has four high-level steps:

- Prepare the digital paper data collection products
- Update the map and/or capture the attribute-value data in the field
- Validate the data
- Import the data back into the GIS system, using one or both of Capturx for ArcGIS and Capturx for Microsoft Excel.

The details of this workflow depend on which attribute-value collection method(s) are used.

2.4.1 Map-based Attribute-Value Update

The Capturx for ArcGIS software enables the user to set arbitrary attributes on both newly-created and existing features. The user does this by interacting first with a Capturx Attributes –action palette” layer that has been added to the legend on the digital paper map (see figures 5 and 6). The interaction method is similar to the standard map feature-class update method. For a new feature, the user would tick that feature class entry on the legend, such as “—mhole” or “—ility pole”, and mark on the map where that feature should be placed. The user would add attribute-value data by next selecting the SET ATTRIBUTE legend entry (see Figure 6) and writing the attribute-value phrase on the map. Note that the phrases can be abbreviated (e.g., “—Diam@36” or “—Col@yellow”). The Capturx for ArcGIS software uses the Microsoft Handwriting engine and various heuristics (such as to handle abbreviations) to recognize the handwritten attribute-value ink.

In order to update an *existing* feature’s attribute value, the user ticks the CIRCLE FEATURE legend entry with the digital pen, which invokes that function on the subsequent ink stroke. This function allows the user to circle a *point* feature that already exists on the map. Once that feature has been selected, the user would employ the SET ATTRIBUTE legend entry to provide the relevant attribute-value data on the map in the form specified below. If the user wishes to supply attribute-value data for a linear or area feature, s/he would tick the INTERSECT FEATURE legend entry, and then draw a line or tick mark on the map crossing the line representing the linear or area feature. Then the SET ATTRIBUTE entry could be used as above.

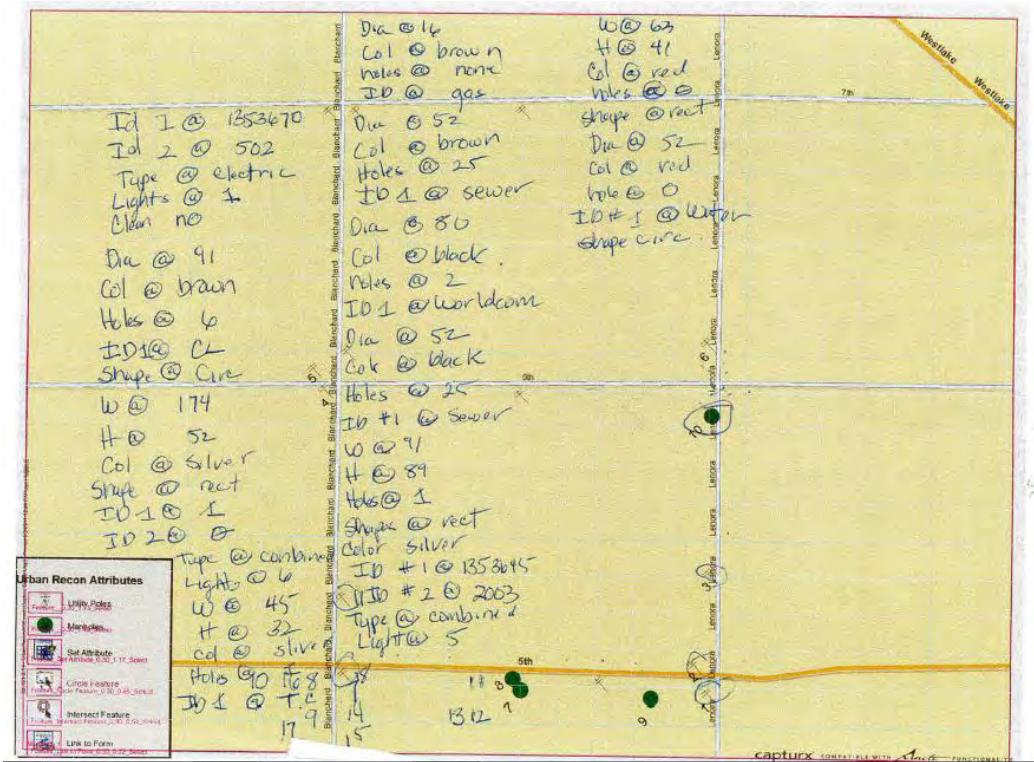


Figure 5. Image of digital paper map with attribute collection legend entries

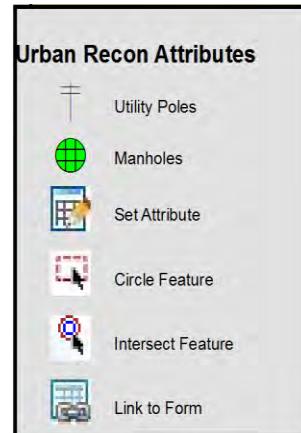


Figure 6. Attribute collection legend

2.4.1.1 Example User Session for Map-based Attribute-Value Update

Below is a sample list of user actions for updating attribute-values on the map.

- Coming across a manhole that does not appear on the map, the user ticks **Manhole** on the legend, and ticks or draws on the map at the proper location to create the feature.
- The user ticks **Set Attribute** on the legend, and writes **-Dia@36"** on the map.³ (The shorthand **-dia"** could either exactly match the Esri field alias **-dia"**, or be a fuzzy match for **-diameter"**.)
- The user ticks **Set Attribute** on the legend, and writes **-Utility@PSE"**.
- The user ticks **Set Attribute** on the legend, and writes **-Tag@465-29A"**.
- Later, upon coming across an existing manhole that needs attention, the user ticks **Select Feature** and then circles that existing manhole on the map.

³ Pilot testing revealed that various separator characters, such as **=**" or **-**", were often misrecognized by the Microsoft handwriting recognition software. It was found that the **@**" symbol provided excellent recognition as a single stroke character.

6. The user ticks ***Set Attribute***, and writes ***-Cover@Missing***.

Note that the user does not need to know that ***-Missing*** will be stored in the database as the number **3**.

Figure 5 shows a map attribute update ***-session***, in which the user added 10 features and updated 6 existing features by writing the attribute-value data on the map.

When the pen is docked, the user will be able to see from the ArcGIS map that a feature has been created, and by inspecting the attribute table, will be able to see that the new feature has three new attribute-values, and that the existing feature now indicates the missing cover.

The Microsoft handwriting recognizer produces a set of ranked handwriting recognition candidates for each word. Currently, when writing attribute-value data on the map itself, the recognized values are not integrated with a handwriting recognition correction interface, so the top recognition candidate as interpreted by the software is chosen. However, the user may edit/correct these values using the writing on the map along with the Attribute Table in Esri's ArcGIS or via the Identify window accessible by right-clicking the created or edited map feature, while inside of an edit-session.

2.4.2 Attribute-Value Update via Linked Forms

Our prototype software supports two additional mechanisms to relate Map features and attribute-value data captured in a form:

- (1) Use of a ***-Link ID*** that is written both on the map and the form
- (2) Use of timing information from the user's ink strokes on the map and form, associating actions that occur close in time (consecutively).

To use form linking, there are three steps:

- 1) Creating the Excel form from the attribute table in ArcGIS,
- 2) Linking the feature on the map to the attribute data in the form
- 3) Importing the form back into ArcGIS.

1). Two form manipulation buttons are added to the ArcGIS command buttons. The user selects the feature class type in the table of contents and then pushes the "+" button displayed at the right. This creates a comma-delimited CSV file for the attribute table for that feature class, which can be imported into an Excel spreadsheet. It also creates the basic data types for each column by inspecting the ArcGIS attribute table. In addition, it also creates metadata that tells ArcGIS how to import the data back from Excel, when the user pushes the import button **↓**, seen at the right. The user can then modify the table and its layout within Capturx for Microsoft Excel, adjusting field datatypes, grammars, and formatting. Each feature class has its own table, and thus its own form.



2). In order to add a value to an attribute of a feature on the map, the user employs another legend item in the Attributes Collection legend called **LINK TO FORM** (see Figure 6). After selecting an existing feature, or creating a new feature, the user ticks the **LINK TO FORM** entry and then turns to the appropriate form page for that feature class, writing the same linking ID on the form as on the map, then filling out the rest of the form. The two form-map linkages that will be employed in the study are described below.

2.4.2.1 Example Attribute Collection Using a Link ID

Here is a simple list of user actions as an example of form-based attribute update with a link ID:

1. Coming across a manhole that does not appear on the map, the user ticks ***Manhole*** on the legend, and ticks the map at the proper location to create the feature
2. On the map page, the user ticks ***Link to Form*** on the legend, and writes ***-4***” on the map next to the created feature.
3. On the form, the user locates an empty row, and writes ***-4***” in the form column of the worksheet under the column-heading —Ink ID”.
4. The user writes ***-36***” in the cell in the *Diameter* column, and writes ***Needs Inspection***” in the *Condition* column.

2.4.2.2 Example Attribute Collection Using Timing

Here is a simple list of user actions as an example of form-based attribute update without a Link ID:

1. Coming across a manhole that does not appear on the map, The user ticks ***Manhole*** on the legend, and ticks the map at the proper location to create the feature
2. The user writes ***-36***” in the cell in the *Diameter* column, and writes ***Needs Inspection***” in the *Condition* column

2.4.2.3 Importing the Data Back into ArcGIS

Once the attribute-value data has been captured in the field, it needs to be imported. This is a two-step process: importing first into Capturx Forms for Microsoft Excel, and then importing into Capturx for ArcGIS.

- a) For each *form* written on in the field, the corresponding Excel workbook must be opened using *Capturx Forms for Excel* and the ink data should be imported. At this time, the user should correct all recognized attribute data, as well as any link ID’s used. The corrected form is then saved.
- b) For each *map* written on in the field, the user should import the ink into Capturx for ArgGIS Desktop. Attributes linking ID’s should be corrected manually in the open edit session and saved. For each form written on in the field, the user should select the new IMPORT CAPTURX FORM tool and select the appropriate workbook. All worksheet pages that correspond to the current map will be imported in the geo-database using either linking ID and/or timing information.

2.4.3 Advantages and Disadvantages of Each Attribute-Value Method

- **On Map advantage:** By writing on the map, the user can maintain focus on one interface, avoiding the flipping of pages.
- **On Map disadvantages:** Currently, in the mapping system, attributes are not integrated with any correction interface, so the top handwriting recognition candidate is always used. However, the user may edit using the Attribute Table or Identify window inside of an edit-session at any point. The map may become cluttered, obscuring other important features. The user needs to write ***<attribute>@”*** for each attribute-value to be entered, which can be verbose. There are ways to encode such writing, however that would require additional training.
- **Form-linking advantages:** Because the user is writing a link ID on the map next to the feature and on the form, it is easy for a human to determine what features correspond to which attribute row in the form. Using timing alone, a human reader cannot determine this. In order to support

the updating of existing features, Link ID's can be pre-assigning to items in the DB and pre-printed in the form.

- **Form-linking disadvantage:** Because the user is handwriting a link ID on the map next to the feature and on the form, there are two chances for recognition error that could lead to the link ID's not matching, or colliding with a previously recognized ID. The user must make sure at import-time of the forms and maps that all data is recognized correctly or corrected by the user.
- **Timing advantage:** Use of timing requires no “verb” selection from the legend palette, and less writing for each attribute collected
- **Timing disadvantage:** The user may become distracted and not write in the form after creating the feature, may tap a form row (thus assigning it) by mistake on the way to the target row, or may not realize what row to return to later to complete any missing information

Given these various methods with no *a priori* choice of the best one to use, a study was undertaken to investigate the strengths and weaknesses of these three methods in actual field use.

3. Study

3.1 Materials

Subjects were given a digital paper map of a 6 block region of Seattle, Washington, printed from Capturx for ArcGIS, a digital pen, and Excel tables for two feature types (manholes and utility poles) for each of two method types requiring them, printed from Capturx Forms for Microsoft Excel, with ID, attribute, and value columns. (See Figures 4a, 4b, and 5).

Printed on the map were legend items for the relevant feature types, the attribute-value legend, and identifiers for existing features. In order to investigate the utility of the various methods for existing map features, a table that included the appropriate existing features' attribute-values was provided (for the LinkID method).

3.2 Subjects

Twenty-four participants (12 male, 12 female) were trained and tested. All participants rated themselves as “intermediate” users of technology, implying that they understand how most current technology works (i.e.: texting, internet, etc.), but lack knowledge of underlying theory. The ages ranged from 18 to 63 years, with a mean age of 32.8 years. All participants completed at least a high school education, with the majority (22 of 24) either enrolled in a bachelor’s degree program or with a completed bachelor’s degree.

3.3 Tasks

Subjects were told to locate 50 given objects in a 6-block radius (12-13 in each condition, and 10 to be located according to the user’s preference), and update the map/tables with their attribute values accordingly.

3.4 Procedure

3.4.1 Design A within-subject counterbalanced design was employed. Each subject traversed the 40 features of the course in the same method order that they were trained. After inputting those 40 features, they were asked to choose a method type and to complete the collection of the remaining 10 features.

3.4.2 Training Each subject was trained by the research assistant following the script in Appendix A, until s/he was able to perform 3 correct instances of each method consecutively. The length of the

practice session was timed for each method type and for an overall training time value. The order of learning each method was counterbalanced along with the method orders.

3.4.3 Intervention Protocol The research assistant (RA) did not intervene during the test (course) portion to assist the subject with the data collection methods. The measurement of coordinates (via GPS) of each feature was performed by the RA during the course for later validation purposes (geospatial error). Notes were also taken during course by the RA. These included: number of requests for help, protocol deviations, relevant subject comments, and other relevant data/events during the course (ie: inclement weather conditions). Intervention was allowed by the RA after three (3) consecutive categorical errors by the subject. The intervention was annotated in the RA notes as well as the corrective action, and was reviewed during the analysis.

3.5 Measures

1. *Time to train to criterion* — The time required to train a subject on how to use each method. The success criterion adopted for training a method was that the subject be able to enter three correct attribute-values consecutively for that method. Times spent training on procedures unrelated to the specified methods were removed, with the same designated script read to each participant. Overall training included not only the indoor/outdoor training in the specific method, but also training on the digital pens, and the specific study criteria.
2. *Time to enter each attribute-value* — The time to enter each attribute-value was calculated separately for *existing* vs. *new* features. Because the digital pen captures the time of each stroke, the research assistant created an Excel spreadsheet from Capturx for Microsoft Excel (see Appendix B), which enabled her to check a box when the subject started entering a given feature, and to check a second box when the subject finished. The software automatically calculated the time difference.
3. *Overall error rates* — Error rates were calculated per method type. They were recorded as means across all of the subjects and features recorded based upon the number of errors per possible used cells. This error rate gave an overall baseline of the errors for each method type, which was further broken down by specific error and format types for each method (see below).
4. *Procedural error rates* — Procedural errors included forgetting to tick the SET ATTRIBUTE legend entry, accidentally creating additional features, etc. Procedural errors were counted based upon the number of features recorded per method per subject. They denote the broadest class of errors and could affect the total number of features recorded by the subject.
5. *Recognition error rates* — Handwriting recognition could create errors, e.g., recognizing a “2” where a “7” was written. Recognition error rates were calculated at the word level as a percentage of attribute-value entries. For each subject the total number of cells per spreadsheet and the number of possible map attributes was computed. For the forms, this took into account all possible cells that could be filled in relative to the specific feature recorded/measured. For writing on the map, this took into account each attribute-value being entered on the map. The types of possible errors included recognition errors for general text, for numerical values, for pre-determined word lists
6. *Fill-in errors* — For Excel worksheets, a value is present where none was expected; on map sheets, an incorrect load from the Excel worksheets.

Each error type was recorded separately for each method type. Note that procedural errors (e.g, the subject's not ticking SET ATTRIBUTE on the map legend before trying to update an attribute)

would lead to recognition errors since erroneous data would be entered into a cell and likely misrecognized. Such instances counted as one procedural error, but not recognition errors.

7. *Time to validate* — Validation was performed by the research assistant, who was considered an “expert” software user. From the pilot portion of the study, it was determined that the subjects would not validate their own results, because the length of time to do so would have been extensive in training and actual performance. The time for validation included the time for identifying the errors, recording their existence, and “fixing” the errors to the correct value. In particular, if a procedural error was made, it could lead to a cascade of recognition errors. Thus, “fixing” the procedural error might involve moving one or more values to the proper field in the attribute table or Excel spreadsheet. Notice that the correction of recognition errors within the Excel spreadsheet could take advantage of the Capturx Review Pane within Capturx Forms for Microsoft Excel. However, there was no comparable recognition review method for the map system. The validation time was recorded with a 3-button stop watch.
8. *Number of requests for help* — this measure was tabulated based on the number of requests for help per method type divided by the number of features entered for that method type.
9. *Geospatial error* — Subjects recorded the location of their features on the map sheet by ticking the feature class entry on the legend and then marking the map with where they determined the feature corresponds. The research assistant recorded the location of each feature by recording the center of mass coordinates as measured by a global positioning system (Trimble’s Yuma Virtual-GPS, Version 0.0.1.26; accurate to 1.0 ft). The distance between the two measurements was calculated using The Federal Communications Commission web-calculator (<http://www.fcc.gov/mb/audio/bickel/distance.html>), and then converted from km to ft. The map zoom level was 1:1,272.
10. *User preference*: Based on the pilot study results of qualitative questioning with 20 subjects, it was decided to break user preference into four specific categories, plus an “overall preference” category. The four categories were: organization, neatness, timeliness, and simplicity. A 5-point Likert scale was used to assess the user’s preference for each method type, with the “overall” category weighted by a factor of four (see Appendix B).

3.6 Hypotheses

Based on the method types and workflows, the following hypotheses were made:

- Writing a linking ID in a form and on the map will be slower and cause increased procedural errors, but will produce the most accurate recognition results
- Writing the attribute/value information on the map will be faster and have fewest procedural errors, but will be more crowded and cause more segmentation and handwriting errors
- Temporal association will be faster than LinkID because there are fewer steps
- Temporal association will lead to procedural errors and be less preferred because the artifacts do not indicate by themselves how the attributes are linked to the features.⁴
- Subjects will prefer writing directly on the maps because there are fewer steps

3.7 Results

We will refer to the methods as:

- Method type L: using a linking identifier

⁴ This hypothesis was made before it was determined to separate out the data collection from the validation by having different people do these steps. This turns out to be the more typical work practice.

- Method type T: using timing information between map and form update
- Method type M: writing on the map
- Method EL indicates method L for existing features, and similarly for ET and EM

1. *Training time to criterion:* The means for each training time were as follows: **Method L-10:51**, **Method T- 7:06**, **Method M-15:03**. These training times showed significant differences among the methods (ANOVA, $F(2, 23) = 4.14$, $p < 0.0001$). Each pair of methods was compared in a secondary analysis (L-M, L-T, and M-T), all of which proved significantly different (L-M: $F(1,46)=14.76$, $p < 0.001$; L-T: $F(1,46)=12.96$, $p < 0.001$; M-T: $F(1,46)=48.27$, $p < 0.000001$.) The mean training times per method can be seen in Figure 7.

An analysis of order effects revealed possible differences in training times among the methods (ANOVA, $F(2, 23) = 55.55$, $p < 0.0001$). The only significant order effect was among the training times for Method T when that method was trained last, which was significantly faster than when it was trained first or second ($F(5, 18) = 4.17$, $p < 0.05$).

The mean time for overall training for the 24 subjects (summing over all methods) was 59:51. No gender, occupational, or age trends were noticed in the training times.



Figure 7. Overall training time to criterion.

2. *Time for entire workflow –*
 - Time to enter a new map feature and its attributes:* The mean times to record new features and their attribute values for each method are as follows: **Method L: 48 sec.; Method T: 39 sec.; Method M: 1:03** (See Figure 8). Analysis of variance (ANOVA) revealed that there was a significant difference in time for data entry among all three method types for new feature collection ($F(2, 69) = 18.15$, $p < 0.0001$). The methods were compared individually in the ANOVA: Method T was found to be significantly faster than L ($F(1, 46) = 8.58$, $p < 0.01$); Method L was significantly faster than Method M, ($F(1, 46) = 10.57$, $p < 0.005$); and Method T was significantly faster than Method M, ($F(1, 46) = 32.26$, $p < 0.0001$). No order effects were found.

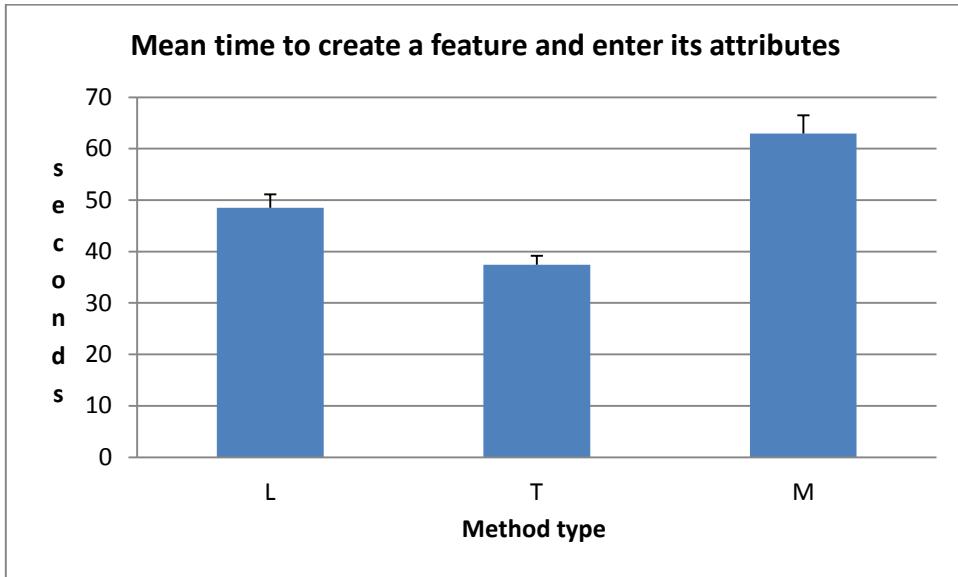


Figure 8. Mean time to create a new feature.

b) *Time to enter attribute values for existing map features:* Each method was used by each subject for corrections to existing features at least twice per method (i.e., at least six times total per subject). The mean times across all subjects for performing updating attribute values for existing features are as follows: **Method EL: 39 sec.; Method ET: 49 sec.; Method EM: 1:01** (See Figure 9), which are significantly different when compared in an ANOVA ($F(2,69)=8.58$, $p<0.00005$). More specifically, attribute-value update with Method EL was found to be significantly faster than with Method EM (ANOVA, $F(1, 46) = 15.75$, $p<0.001$). The primary factor that influenced this difference was that for Method EL, it was only necessary to overwrite the data in the attribute table, whereas the user of Method EM had to select the feature and write the new attribute/value. No difference was found between Method ET and the other two method types, and ANOVA revealed no order effects.

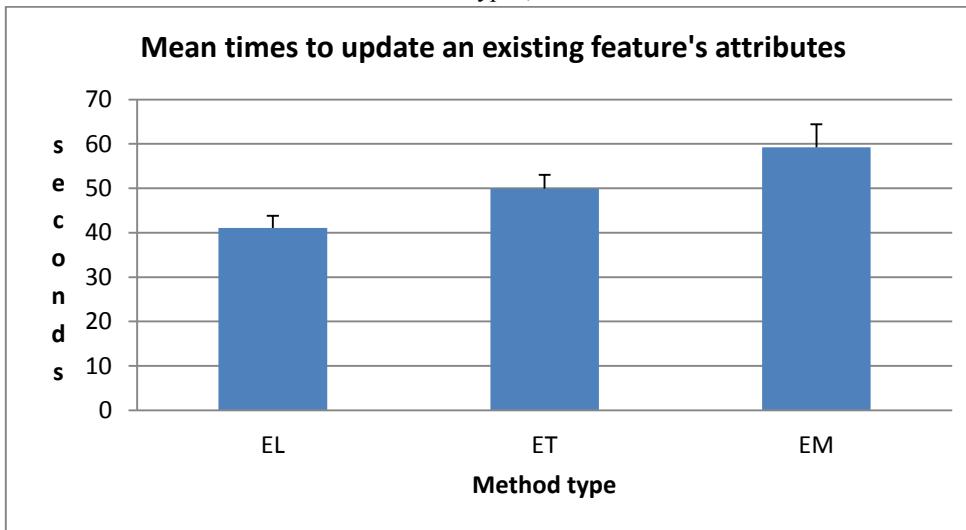


Figure 9. Mean time to update an existing feature.

3. *Overall error rates:* The mean overall error rates, including both recognition and procedural errors, per method type were as follows: **Method L: 0.032; Method T: 0.050; Method M: 0.251** (See Figure 10). Compared cumulatively in ANOVA, there were found to be significant differences in the

error rates ($F(2, 15) = 12.6$, $p < 0.0001$), with Method M showing significantly more errors than either Method T or Method L ($F(1, 8) = 41.5$, $p < 0.001$), ($F(1, 8) = 40.9$, $p < 0.0005$) respectively. The difference in error rate between Method L and Method T, was also statistically significant ($F(1, 46) = 5.68$, $p < 0.05$).

4. *Procedural error rates:* The number of procedural errors per method type was recorded as an independent data set, and by method type. Method L had a cumulative procedural error rate over all subjects of 4% of possible cells recorded. This largely reflected subjects' not selecting the LINK TO FORM legend entry after determining a linking identifier to link the map sheet to the attribute table in Excel, or selecting that legend entry in an incorrect order. Subjects had no errors using Method T. Method M had an error rate irrespective of the number of features recorded: Thirty-eight extra features were marked on the map that did not correspond to any attribute value data, as compared to the 299 new features recorded using method M that did correspond to attribute value data (procedural error rate of 12.7%). The procedural errors for method M were primarily the subject's making a mistake during data collection and subsequently performing the feature placement again.

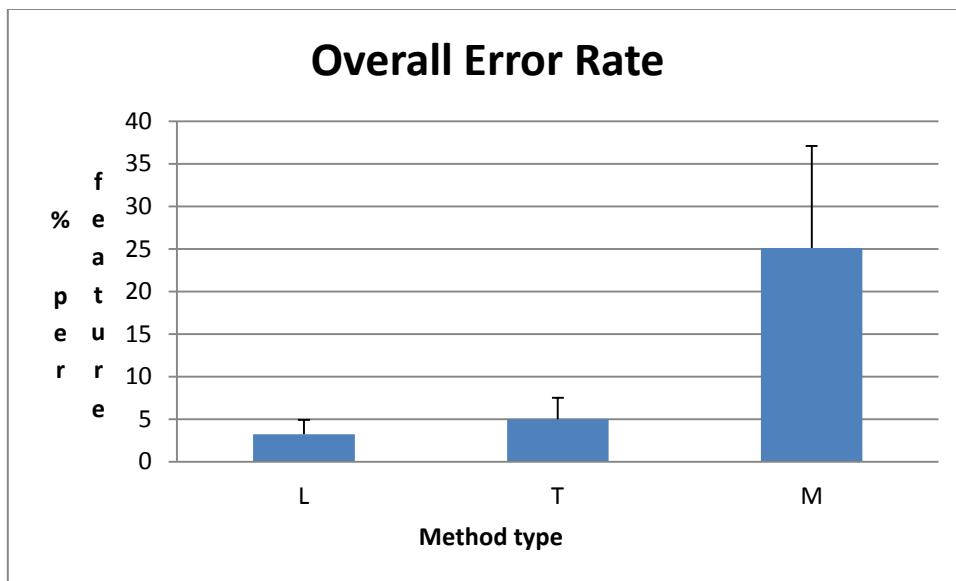


Figure 10. Overall Error rates

5. *Recognition errors:* The recognition errors across the different Method types are as follows: **Method L: 3.2%; Method T: 5%; Method M: 25%** (See Figure 11). Method M showed significantly more errors than either Method T or Method L. In addition, Method L and Method T were significantly different ($F(1, 46) = 1.19$, $p < 0.05$).

Recognition Error type	L: #errors/ total errors	% L errors in each category	%L errors per A/V cell (n=4097)	T: #errors/ total errors	%T errors in each category	%T per A/V cell (n=3749)	M: #errors/ total errors	% M errors in each category	%M per A/V cell (n=2262)
Free text	113/125	90.4	2.7	172/184	93.5	4.5	389/466	83.5	17.2
Word List	5/125	4	.12	7/184	3.8	.19	77/466	16.5	3.4
Numerical									
Fill-in	7/125	5.6	.17	5/184	2.7	.13	0	0	
Procedural errors (per feature)	11/265	4		0/407	0		337 observed, 299 expected		

Figure 11. Error rates across method types.

Recognition error rates (as percentages) were compared across the different formats of Excel spreadsheet cells and map sheet attribute table cells for three different types of recognition errors: numerical, word list, and general text. The percent error rates for the Excel spreadsheet cells were, respectively, 3.0%, 1.6%, and 14.9% (See Figure 12), which were found to be significantly different (ANOVA, $F(2, 60) = 9.45$, $p < 0.001$). A follow-up ANOVA was also run between of each pair of error types. There was no significant difference found between the word list error rates and the numerical error rates for this population within the Excel spreadsheet cells. However, the word list error rates and the general text error rates were found to be significantly different (ANOVA, $F(1, 40) = 10.5$, $p < 0.005$), as were the numerical and general text error rates ($F(1, 40) = 9.29$, $p < 0.005$).

For the map sheet attribute table cells, the three types of recognition error rates were also calculated (numerical, word list, and general text), yielding 11.6%, 6.5%, and 24.2%, respectively (See Figure 12). An ANOVA was run among these three different types of recognition error rates for the map sheet attribute table cells and also between the pairs of each recognition error type. No significant differences were found.

	Numerical: # errors/total # numerical cells	% Numerical Errors	WL: # errors/ total # WL cells	% Word List Errors	General text: # errors/ # total general cells	% General text Errors
Excel spreadsheet cells	98/3401	3.0	21/1307	1.6	159/1068	14.9
Map sheet attribute table cells	360/3108	11.6	119/1825	6.5	360/1490	24.2

Figure 12. Error rates across the sheet types (not the methods).

6. *Fill-in errors:* No significant differences across methods were found in the number of fill-in errors.
7. *Time to validate:* For each subject the total number of cells per Excel spreadsheet and the number of possible map sheet attributes was recorded for a baseline measurement. For the Excel spreadsheets, this took into account all possible cells that could be filled in, relative to the specific feature recorded/measured. For the map sheets, this took into account each line of written text on the map

sheet individually and how accurately it filled into the attribute tables. The types of errors possible/observed per cell included recognition errors for general text and for pre-determined word lists, and fill-in errors (see section 3.5). Each error type was recorded separately for each method type. The mean times (minutes:seconds) for data validation for the three different methods are as follows: **Method L (1:25), Method T (1:36), Method M (19:23)**. These validation times were considered significantly different when all three times were compared in ANOVA ($F(2, 12) = 41.03, p < 0.0001$). While Methods L and T were clearly different from Method M, Method L and Method T were not found to be significantly different when compared alone with respect to validation times.

8. *Number of requests for help:* Of all of the requests for assistance, the majority were for Method L (33), with five assistance requests made for Method T, and 11 requests made for Method M. The rates per method per *feature* created or updated are as follows: **Method L: 10%; Method T: 1%, and Method M: 3%**. The assistance requests made were primarily appeals for workflow reminders. For method L, the assistance requests made related to subjects' not remembering the proper order in which to link the map sheet to the Excel spreadsheet(touch LINK TO FORM, assign a number on the map sheet, assign the same number on the Excel spreadsheet).
9. *Geospatial error:* Of the 24 subjects, 21 subjects showed consistent placement of features, with a mean distance of 7.3 feet with a standard deviation of 7.1 feet (showing most estimated locations were between a distance of 0 feet and 15 feet from the "actual" location). This represented approximately 1048 features. Three subjects' geospatial data was left out, because of excessive error, such as placement of features on the wrong street or the wrong side of the street. These subjects were referred to the intervention protocol during the testing. However, their geospatial data were considered as outliers. The map zoom level of 1:1,272 inches or $1'' = 106'$, so a mean accuracy of 7.3 feet means the subjects positioned entities accurately within 0.069 inches on the page.
10. *User Preference:* Overall, the stated subject user preference was **Method L: 3; Method T: 17; Method M: 4**. While Method T was the clearly preferred method, the actual demonstration of user preference (based on which method the subject chose to use for the last 10 features) was as follows: 2(L), 16(T), 6(M). Most subjects (but not all) were aware of what they in fact preferred.
11. *Miscellaneous:* It was noted that inclement weather may have affected handwriting clarity (neatness), particularly if gloves were worn during the data collection. Of the five subjects who wore gloves during data recording, significantly higher error rates in handwriting recognition were found (ANOVA, $F(5, 12) = 0.44, p < 0.05$). However, in determining specific patterns for why this was so, no significant difference between the method types could be discerned. In fact, two subjects, neither of whom wore gloves, provided the highest number of errors due to poor handwriting and a slightly skewed orientation). No particular trend was noticed between genders or occupation with respect to who wore gloves or had excessively bad handwriting. Overall, no particular trend was noticed between genders or occupations for this study.

4. Discussion

Figure 13 summarizes the findings of the study. Typically, lower values are better than higher. Statistical significance of each finding is listed in the last column. In review of the expected versus the observed results, it was found that not all of the originally-postulated hypotheses held.

- *Speed of attribute-value data entry:* It was originally hypothesized that Method L would be the slowest in recording new features, while Method M would be the fastest. However it was observed during the testing that Method L was neither the slowest nor the fastest, and Method M was actually the slowest. This is most likely due to the necessity of writing not only the attribute value on the map sheet, but the attribute type

itself (i.e., attribute@value) during Method M. Figure 13 shows the speed of the method types as T<L<M. For existing map features, method L was faster since the user needed only to find the appropriate row in the table via the LinkID and to update only the appropriate attribute value. Method T required the user to rewrite the entire row of attribute-values.

- *Procedural Errors*: It was hypothesized that Method L would have more procedural errors, while Method M would have the fewest procedural errors. The results showed the opposite, that Method L had neither the most nor least procedural errors while Method M had the most procedural errors (12.7%) because of erroneous/accidental creation of features.

It was hypothesized that Method T would lead to more procedural errors, but in the context of this study, it led to none. In actuality, it had the fewest steps for subjects to track. However, that particular hypothesis could be indicative of the validation procedure (as a whole for time) as well.

Method L was the fastest to validate because the artifacts did indicate in a timely manner which data in the Excel spreadsheet charts belonged to which map sheet point features. Validation for the other method types was much more difficult, because each line written on the map sheet had to be analyzed carefully, and each unlabeled point feature matched with its corresponding data.

- *Recognition errors*: Method L did have the least, as originally hypothesized. The recognition error rates showed variability within each method, as evidence by the results, and also across each format. It would be inappropriate to compare recognition error rates between the formats because Capturx for Microsoft Excel and Capturx for ArcGIS used different handwriting recognition programs. However, in prior tests, we have found these recognizers to deliver essentially equivalent performance across lists, numbers, and general text.

With respect to all of the attribute data that was written on maps for Method M, it should be noted that there may have been skewing of the data because of variable handwriting orientation. Although they were counseled to write as horizontally as possible, subjects may have had a more difficult time writing in the correct orientation in this format because there were no discernable writing guides. Furthermore, the subjects had to write the attribute “type” first, and if it was written incorrectly or was unrecognized by the recognition program, the attribute-value was not filled in appropriately. Since all three types (word list, numerical, and general text) of recognition data were written this way (attribute@value), this may be the reason why no recognition error differences were found between these data types.

- *User Preference*: It was hypothesized that the subjects would prefer the Method M because writing on the map has fewer steps. Overall, the subjects stated that they preferred Method T, and mostly for the same reason that was assumed for Method M: it supported the fastest performance.⁵ However, in bad weather (windy, cold, rain), subjects preferred Method M because there were fewer papers to manipulate.

In the survey that was given after the subjects performed their 50-feature collection, the categories of organization, simplicity, neatness, and timeliness came up as the factors that were important with respect to why they preferred one method over the others. These factors were not ranked with respect to importance to the subjects, but they were given numerical weight. The discernable patterns that this data described were only related to the timeliness. The subjects all considered Method T the quickest to use for data collection.

⁵ Notice that is as an extra step over method M, namely switching to the form, However, the extra handwriting likely was slower than flipping pages.

Measure	L	T	M	Statistical Significance
Fastest time to train	2	1	3	Methods are significantly different; T is significantly faster when last (vs. first or second)
Fastest time to enter each new feature and attributes	2	1	3	Significant overall, significant differences between all pairs of methods
Fastest time to enter correct existing features and attributes	1	2	3	Significant overall, Significant difference between only EM and EL
Overall error rates (Least=best)	1	2	3	Significant overall, biggest significant difference between M and others, small sig diff between others
Procedural error rates (Least=best)	2	1	3	N/A
Recognition error rates (Least=best)	1	2	3	Significant difference between L & T only
Fastest time to validate	1	2	3	Only significant when overall
Number of requests for help (Least=best)	3	1	2	N/A
User preference practiced during testing (Most=best)	3	1	2	N/A
User preference stated after testing (Most=best)	3	1	2	N/A

Figure 13: Comparison of Method Types

The upshot of this analysis is that temporal linkage is both a robust (no procedural errors) and preferred method for the field data collector. However, it is clear that the LinkID method will be advantageous for the data validator. LinkIDs are also advantageous for updating existing features. By combining both of these methods, a robust method can be built that meets the concerns of both stakeholders. The combined method would be simplest by treating temporal linkage as primary, with the LinkIDs being used in a secondary fashion. They are useful for the validator if there is need to correct any information that is misdirected. A formal join is not necessary. Given that there are two opportunities for handwriting recognition failure with the LinkIDs when creating new features, the temporal linkage will be most robust, provided the user obeys the temporal constraints of selecting a feature, ticking the set attribute legend entry, and filling out the form.

5. Related Work

The standard way to collect GIS attributes is with a handheld device, such as Esri's ArcPAD, Trimble's Nomad, or TerraGo Mobile software running on a Tablet PC. For the US Census 2011 address canvassing survey, Harris Corporation built a special purpose device. In general, such mobile devices can require significant training, cost, field service, software integration, and are objects of distraction and theft. Smartphones and tablets currently are popular devices, but share many of the aforementioned issues. For these devices, the user alternates between map and form, since most of the devices have minimal screen territory. However, for many field users, especially those who are brought into the data collection task quickly, such as during an emergency, paper maps and forms are the simplest work practice to train and deploy.

A number of research efforts have experimented with digital paper maps, including RASA (McGee et al., 2001, 2002; NISMap (Cohen & McGee, 2004), and Norrie & Signer (2005). However, these systems did not integrate with a full geographical information system, and thus did not have the problem of providing attribute-value data.

There are a number of vendors of digital paper forms on the market (e.g., Destiny Wireless (<http://www.destinyplc.com/flash/#/home/overview/>) , MiCo (<http://www.mi-corporation.com/>) , Expedata <http://www.expedata.net/industry/industry.html>) , virtually all of which employ the Anoto forms toolkit (<http://www.anoto.com>). These forms tools are not populated by a GIS system to automatically create an attribute table, nor have they been used to collect data that is returned to a GIS system.

6. Implications and Recommendations

The results of this study indicate that each method has its own strengths and weaknesses. From the perspective of the field data collector, who were the subjects of the study, the time-based method was a clear winner, supporting the fastest performance with the fewest procedural errors, leading to the highest user preference. We initially were concerned that the inability for the GIS data validator to be able to link the row of the attribute-value table with the feature on the map would lead to confusion. In principle, this does still appear to be possible, but this small study, which used only one validator, did not address the issue.

The LinkID method supported the fastest performance for updating existing features. Surprisingly, though we had thought it would be the most reliable method (though from the perspective of the validator), it turned out to have significantly more procedural errors than the time-based method, and more requests for help. This was due to the fact that the method required that the legend entries be selected in the right order (first circle the feature, then select the LINK TO FORM entry, etc.). Subjects either made order mistakes, or they requested help to remember the proper order. Other user interface designs could perhaps avoid these issues.

Linked and time-based forms may be used at the same time. Separate linked (with link column) and time-based (without link column) forms may be printed and used for the same or different feature classes and used in any order. A single form (containing a link column) may be used for both linked and time-based collection. If the user forgot to link cells explicitly, the system could fall back on timing. For example, the software could use valid timings to assign rows; otherwise it could fall back on Link ID's – so time would always be preferred unless the user waited over 60 seconds to touch a row after creating a feature. Link ID rows could also take precedence. However, this may be confusing to both the user and the software, because some link cells may be empty while others are filled in, and there could be a conflict between the two methods if the user creates a new feature with a Link ID, and then writes a different Link ID in a new row. One way to address this would be to have a new mode that uses both Links ID's and time, but uses each to reinforce the other – both methods must agree, or the import process can flag a possible error. This would give the advantage of the map and form artifacts of Link ID, but would flag any recognition error of the Link ID's not matching. A user study could determine if such potential issues arise in practice.

For configuration and circumstances of data collection explored here, with two or more attributes to be collected, the writing on the map method was inefficient. It tends to be more labor intensive not only for the field user but for the validator as well. It may be best in circumstances where only one attribute per feature is to be collected, or in bad weather, when flipping between pages and formats would be unnecessary or undesirable, and the data matching between the formats would be obvious. Further, for expert users of this attribution technique, there could be other methods of encoding the way the data is written on the map sheet (e.g., instead of attribute=value, write value@value@value when the values are unique enough that the related attribute can be inferred reliably). Either or both of the form-based

approaches can also be used with on-map attribute collection, as described in Section 2.4.1. The requirement to write horizontally in landscape orientation is a temporary one, with future iterations of this software potentially taking advantage of automatic baseline detection. Still, writing on a dense map can obscure important information that may be needed at some future time. Last, without a correction experience for the map sheet akin to the correction available for the Capturx-enabled Excel spread sheets, the efficacy of this method type is further decreased, especially for the validator.

7. Conclusion

The *temporal linkage* method between the data collection formats was overall the fastest and most preferred attribute-value update method for this study.

All three of the methods tested could be successful in specific circumstances that would engage their strengths during attribute collection, including the physical situation of data collection. The use of all three of these methods, based upon the field user's attribute collection needs at any given time, may be possible and prove optimal. It must be noted however, that implementation of all of these methods in a combined technique may prove more difficult.

Finally, this study concentrated on the field data collector. If it had considered more heavily the needs and workflow of the validator, the performance of and preference for each method might be different. Ultimately, the preference for the method to be used is up to the organization and the criteria they wish to optimize. This study exposes some of the issues that need to be considered.

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Appendix A: Training Script

1. SIGN INFORMED CONSENT FIRST- Please read the Informed Consent forms (2), and I will answer any questions that you have.
2. RA: sign IC forms also, determine method order from script
3. (To be read to subject): The Study is titled Soldier as a Sensor. This is sponsored by the Army Corps of Engineers. The purpose of this study is to compare the use of three (3) different methods of data collection with the digital pen. This data will be comprised of major features such as manhole covers, and utility poles. In these methods, you will be making marks on a map that represent an object and then filling in things about that feature, such as color, width, length, and identifying marks either directly on the map or on a spreadsheet. These three methods will be physically shown to you inside during training, which will take about 20 minutes. Next, you will practice outside using these on the street, which is similar to the test route. Outside, you will train until you demonstrate proficiency, which is three features and their attributes recorded correctly per method (at least 9 total). Last you will perform the test using 50 different features on the pre-designated route. This is actual study portion. The time it takes for you to measure/record all of the data will be timed. Remember, it is the method that is under scrutiny, not you personally. I will be following you and taking GPS measurements of the features, for later comparison between the equipment used. Each point must be measured, no “copying” is allowed of prior measurements.
4. During the actual course portion I am not allowed to assist you. After the course completion, we will return to Adapx and I will ask you some questions about the methods, training, and course. After this, you will be released. As per our study guidelines, we are budgeted 2-3 hours for completion of both training and execution of the course. You will be compensated a set amount of \$50 for this.

Show and tell:

5. Digital pen- This is the digital pen (penx). This pen acts as a recording device for strokes that are made on a digitally-rendered paper. Charts and maps are watermarked to act as “live” databases. So you make a mark on the watermarked paper, the pen records it, and when you are finished recording all of your data the pen is docked into a station. That data is then uploaded from the pen by me into pre-designated databases (after your part of the study is completed). Proper orientation of the pen on the watermarked paper is important: the camera has to “face” the paper or it will “buzz”. Please only touch the buttons on the page, no excessive marking is necessary, and may degrade the watermarked portions of the paper, making your pen buzz excessively. For the sheets, only the watermarked portions are recorded. Any space outside of the watermark (dots) is not recorded. The sheets must be properly oriented when writing on them as well in order for the test to be recognized appropriately. East-to-west (L-R) is the proper orientation with the top of the page aligned. (Physically shown details).
6. The data that you fill in with your digital pen is considered “active ink”. These markings may be erased by you (such as the eraser on a pencil). In order to perform this function on the spreadsheets:

For cells that need correction-

Cross out the old value of a cell with the digital pen, touch the eraser button, enter new value within the confines of the cell.

For cells that should be empty-

Touch the eraser button, touch the cell.

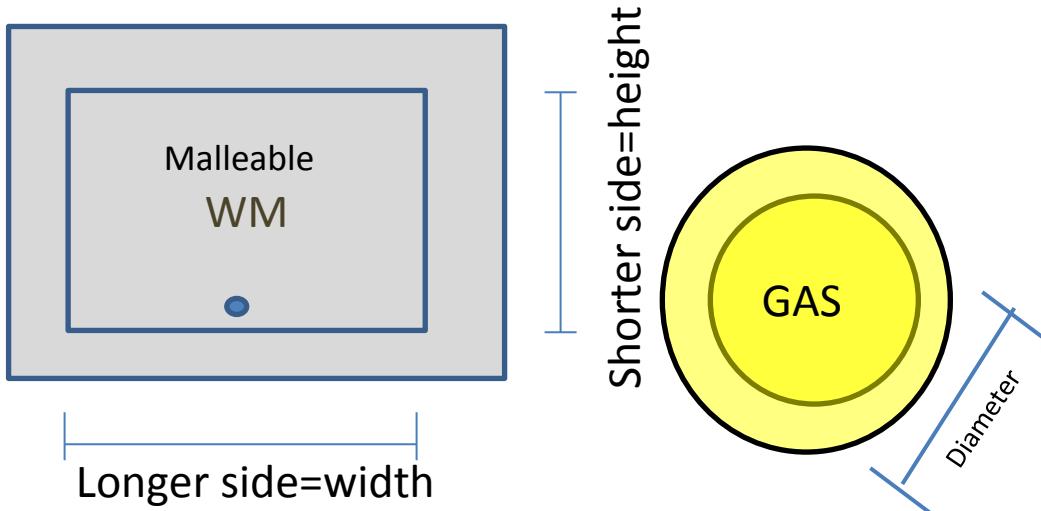
For map sheets, the eraser button is not available for your ink. Please perform the data collection again with the correct method and correct data.

The data that is already filled in your spreadsheets is not considered “active ink”. This is not ink that you have filled in, and therefore may be erased/corrected within whichever method that you are performing.

7. Some terms I may be using: features- the things that we are measuring: manholes, utility poles. There are two feature classes: utility poles and manholes. Existing features are those pre-programmed into the cellx and mapx. Attributes- the stuff we are measuring or recording on the feature: color, height, width, and whether it needs cleaning. This is dependent

upon the actual feature itself. Legend- the bottom left corner of the map that either explains what is on the map, or allows you to choose digital instructions.

When recording measurements for manholes such as diameter, width, or height, you are measuring the interior (usable portion) of the manhole. Please use metric measurements; see tape measure. Due to the differing shapes of the manholes, some data may not be applicable (ie: diameter on a square manhole, width and height on a round manhole) Such as follows:



As was stated, I am not allowed to intervene during the course collection. However, if I note that you have made three of the same consecutive errors, I will intervene and we will continue the course. It will be annotated.

You will be timed for each feature collection. Please wait until the RA says, "Start", and then let them know when you are finished by saying, "Stop" for each feature.

PLEASE TALK THROUGH YOUR FEATURE COLLECTION UNTIL YOU FEEL THAT YOU ARE COMPETENT.

Scenario: Talk through a scenario that may be relevant to the study subject, based upon their demographic. ie: ROTC students, the use of the digital pen and software in a tactical environment; Civilians: the use of the digital pen/software in an airport or by paramedics.

Your method order will be _____. Explain the route on the map. There are 50 points (features) on the course to collect. They are divided by 13(method ____), 13(method ____), and the remainder to 40(method ____). The last 10 will be your preference in method. You are required to collect 2 per method of existing features.

Do you have questions at this time? ***RA: Please present the following Methods based upon the Method Order assigned.

RA: Check Training START TIME

Method L

Method type L is the linking ID. You will have a map and a spreadsheet. Please find the spreadsheet which begins with the column —Ink ID". So you will orient yourself on the map.

For new features: You will touch the feature in the legend (manhole, utility pole, address), draw it on the map with one stroke. This drawing is for you- to help your eye/mind determine what you are putting where. The one-stroke picture is your choice: a circle, a line, a square. Touch link to form, write a number on the map, write the number on the form, and then fill in the attribute data.

Please do not include labels as they are already built in (ie: cm). For colors, the recognized colors are white, yellow, brown, gray, red, black, silver, and other. For utility poles, Kind = UNK/Unknown, TRF/Traffic/Traffic Control/Signal, TEL/Telephone/Telco/POTS, ELE/Electric, COM/Combined/Combo/Multi, BUS/Electric Bus/Bus/Trolley/Train, LAMP

**For existing features, two methods of correction are available:

1. Make a new row, but use the same linking ID as the existing feature.
2. Write the new data in the same row as the existing information; do not change the linking ID.

Practice. Questions?

RA: Check Training STOP TIME

RA: Check Training START TIME**Method T**

Method type T is Temporal Association. You will have a map and a spreadsheet. Please find the spreadsheet which does **NOT** begin with —Ink ID”. So you will orient yourself on the map.

For new features:

You will touch the feature in the legend (manhole, utility pole), and then draw it on the map with one-stroke. This drawing is for you- to help your eye/mind determine what you are putting where. The one-stroke picture is your choice: a circle, a line, a square. Go directly to filling in the chart with the attribute data. The time stamp on the map and the time stamp on the spreadsheet will determine which data goes together (this assigns that feature a row on the chart).

Please do not include labels as they are already built in (ie: cm). For colors, the recognized colors are white, yellow, brown, gray, red, black, silver, and other. For utility poles, Kind = UNK/Unknown, TRF/Traffic/Traffic Control/Signal, TEL/Telephone/Telco/POTS, ELE/Electric, COM/Combined/Combo/Multi, BUS/Electric Bus/Bus/Trolley/Train

**For existing features, we are trying to determine whether the current attribute data is correct. For this method, touch circle feature, then circle the feature on the map. Write the attribute data on the spreadsheet in a new row.

Practice. Questions?

RA: Check Training STOP TIME

RA: Check Training START TIME**Method M**

Method type M is Writing on the map. You will have a map only. So you will orient yourself on the map. For new features:

You will touch the feature in the legend (manhole, utility pole, address), and then draw it on the map with one-stroke. This drawing is for you- to help your eye/mind determine what you are putting where. Touch set attribute in the legend, write the attribute data directly on the map. The way it is written on the map is in the x=y format. For example,

Color@ yellow

Diameter@36

Open@ true/ false, yes/no

Holes@0

No units are written (ie: cm). For attributes that would be checked on a spreadsheet for their presence you would write true or false (ie: open = false; clean=true). For colors, the recognized colors are white, yellow, brown, gray, and other. For utility poles, Type = UNK/Unknown, RET/Retail, OFF/Office, PAR/Parking, FOD/Food Service/Food/Restaurant. For addresses, business type = UNK/Unknown, TRF/Traffic/Traffic Control/Signal, TEL/Telephone/Telco/POTS, ELE/Electric, COM/Combined/Combo/Multi, BUS/Electric Bus/Bus/Trolley/Train

For each subsequent attribute, touch set attribute first and then write it on the map. You may use the attributes listed on the back of your clipboard to determine what may be collected. This list also includes what abbreviations may be used per feature/attribute/data.

FYI, all of the marks that you make on the various map sheets will be downloaded onto one cohesive map sheet with an attached database of the information you recorded. On the computer screen, we will see all of the ink you have drawn, and the assignment of the features on the map. Then we will be able to call up a chart of the attributes as the program has read your writing, so it is important to write neatly and in the correct orientation. You may use as many map sheets as you would like.

**For existing features, touch “circle feature”, circle the feature on the map, touch set attribute, write in x@y form.

Questions? Practice.

RA: Check Training STOP TIME

Appendix B: Research Assistant timing sheet

SUBJECT NO:		INSIDE TNG:	(M):	<input type="checkbox"/>	<input type="checkbox"/>	(L):	<input type="checkbox"/>	<input type="checkbox"/>	(T):	<input type="checkbox"/>	<input type="checkbox"/>
TNG Start:	<input type="checkbox"/>	OUTSIDE TNG:	(M):	<input type="checkbox"/>	<input type="checkbox"/>	(L):	<input type="checkbox"/>	<input type="checkbox"/>	(T):	<input type="checkbox"/>	<input type="checkbox"/>
TNG End:	<input type="checkbox"/>	Totals TNG:	(M):			(L):			(T):		
METHOD ORDER:		Total Complete TNG:									
Course started:	<input type="checkbox"/>										
Feature	Method	Start	Stop	TOTAL	Coordinates						
					Latitude	Longitude					
1		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
2		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
3		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
4		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
5		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
6		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
7		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
8		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
9		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
10		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
11		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
12		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
13		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
14		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
15		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
16		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
17		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
18		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
19		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
20		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
21		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
22		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
23		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
24		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
25		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
26		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
27		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
28		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
29		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
30		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
31		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
32		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
33		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
34		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
35		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
36		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
37		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'					
Notes:											

SUBJECT NO:									
Feature	Method	Start	Stop	TOTAL	Coordinates				
					Latitude	Longitude			
38		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
39		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
40		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
(User pref.)									
41		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
42		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
43		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
44		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
45		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
46		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
47		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
48		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
49		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
50		<input type="checkbox"/>	<input type="checkbox"/>		47°N36'	122°W20'			
Course stop: <input type="checkbox"/>					TOTAL COURSE TIME:				
Assistance Requests: <input type="checkbox"/>									
Method (L,T,M):					TOTAL ea. Method:				
Today's weather:									
User Preferences			Very Accurate	Somewhat Accurate	Neutral	Somewhat Inaccurate		Very Inaccurate	
Q001	I prefer method M for its organization.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q002	I prefer method M for its simplicity.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q003	I prefer method M for its neatness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q004	I prefer method M for its timeliness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q005	I prefer method M overall.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q006	I prefer method L for its organization.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q007	I prefer method L for its simplicity.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q008	I prefer method L for its neatness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q009	I prefer method L for its timeliness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q010	I prefer method L overall.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q011	I prefer method T for its organization.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q012	I prefer method T for its simplicity.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q013	I prefer method T for its neatness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q014	I prefer method T for its timeliness.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Q015	I prefer method T overall.		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	
Notes: (Bio data): year in school/ROTC, program, age, previous experience with technology/navigation, 1st language									

Appendix C: Interface Workflow

Protocol for continuity --Soldier as a Sensor Attributes

Before Testing

Open Nucleus Shortcut

Folders

- e-folder: Copy ‘New User’ folder to maintain integrity of folder , Rename copy to ‘subject number’
- open Excel (Forms/Forms.xlsx) and Esri Maps (UrbanRecon_ACE1/UrbanReconACE.mxd) within current subject e-folder
- Print through Capturx toolbar for Capturx-enabled sheets (water-marked) within Excel program
- Print through Capturx icon for Esri for enabled map sheets

Set digital pens

Set User (subject) number on Pen Man program for continuity of data collection, RA pen= RA+Subject number

Post-testing

Ensure Nucleus is open.

Insert digital pens in docking station, download ink from both into computer. Ink will be located per file in Desktop/Ink Shortcut. Click to process. Cut, paste into user’s file under Ink folder.

Open user’s Excel sheets. Import ink into cells by clicking import ink button. One per sheet will be necessary, or all sheets may be processed per user at the same time.

Review Excel data, comparing to paper sheets. Save.

Import map sheets data by pressing ‘sessions for current map’ radio button. While still in edit mode, review link ID numbers for accuracy in attribute tables of feature classes. Click green (check) accept radio button. Import Excel data into the attribute tables by clicking ‘Import cells attribute data’ radio button. Validate attribute tables for time/accuracy, using corrected excel sheets and paper maps.